Quantifying the influence of vegetation in the radiative budget of urban landscapes using DART

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SMART Singapore-MIT Alliance for Research and Technology

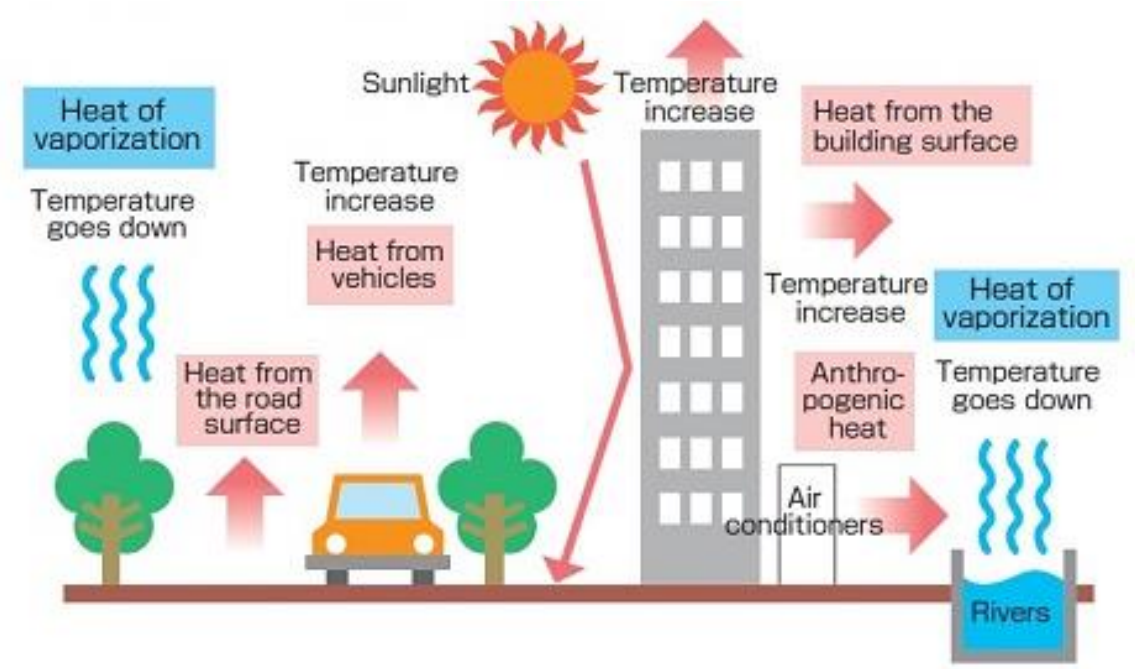
Introduction

- **Urban Heat Island** is the condition where urban areas experience consistently higher air and surface temperatures than the surrounding countryside.

- **Causes**

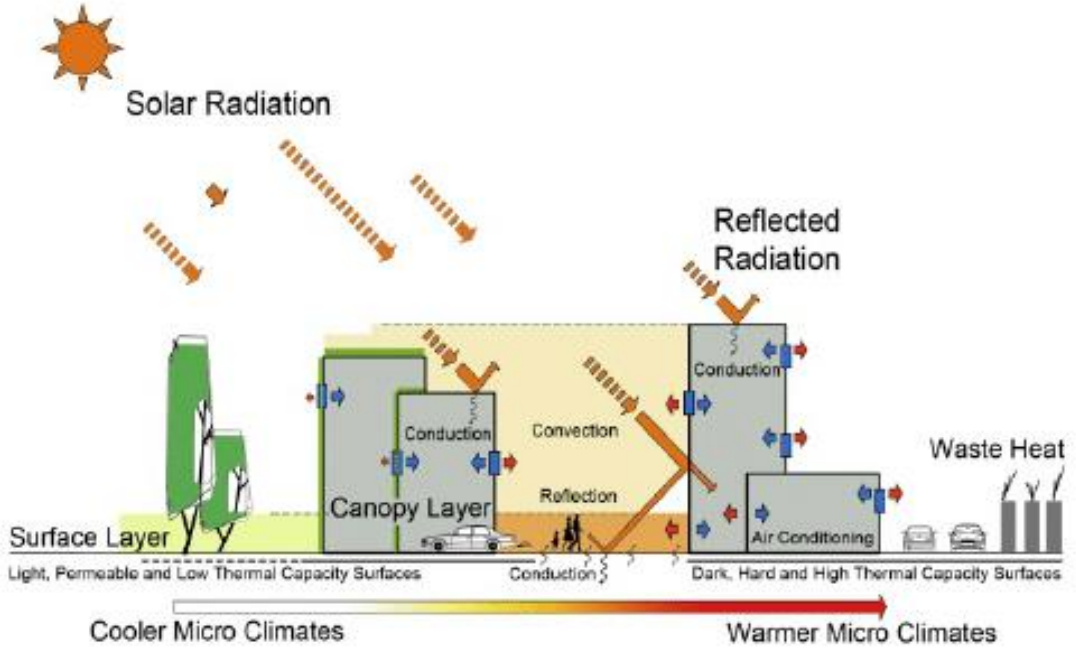
    1. reduced vegetation cover
    2. high runoff from impervious surfaces which reduces soil moisture and evapotranspiration
    3. complex urban geometries that absorb and trap radiation
    4. low albedo urban materials that absorb large amounts of solar radiation
    5. waste heat production from urban activities

- **Aim**
    - Quantify the effect of urban vegetation on the radiative budget.
    - Contribute to the development of climate resilient urban spaces

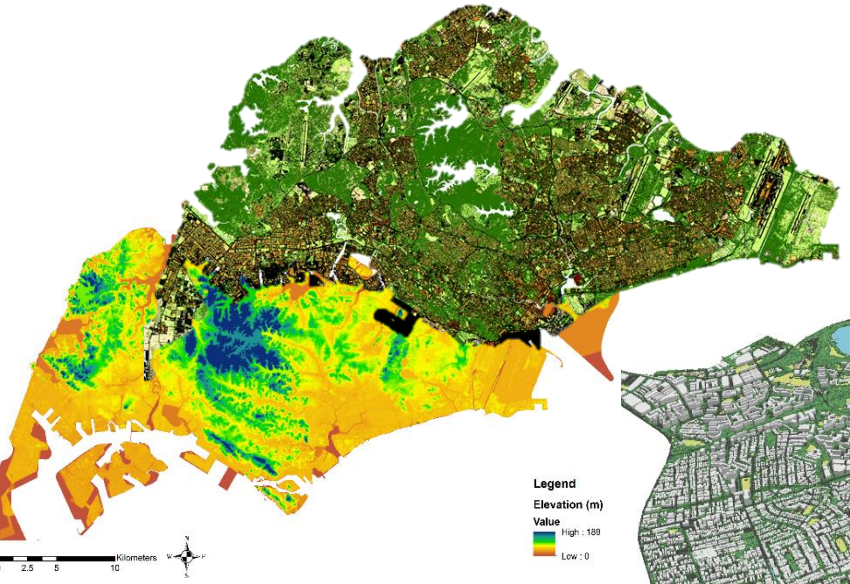


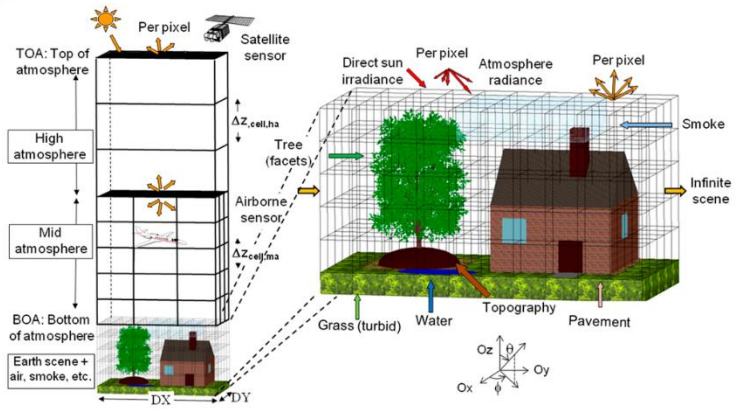
Radiative budget

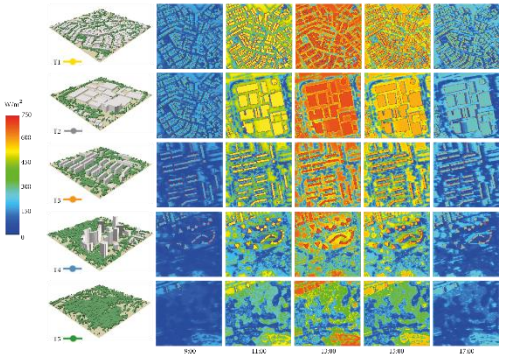
- Key parameter in urban climate models
- Summarizes the interaction between radiation and the urban surfaces
- Directly influenced by urban geometry, surface material, solar incident angle, and atmospheric diffuse radiation.
- Varies temporally and spatially



Overview





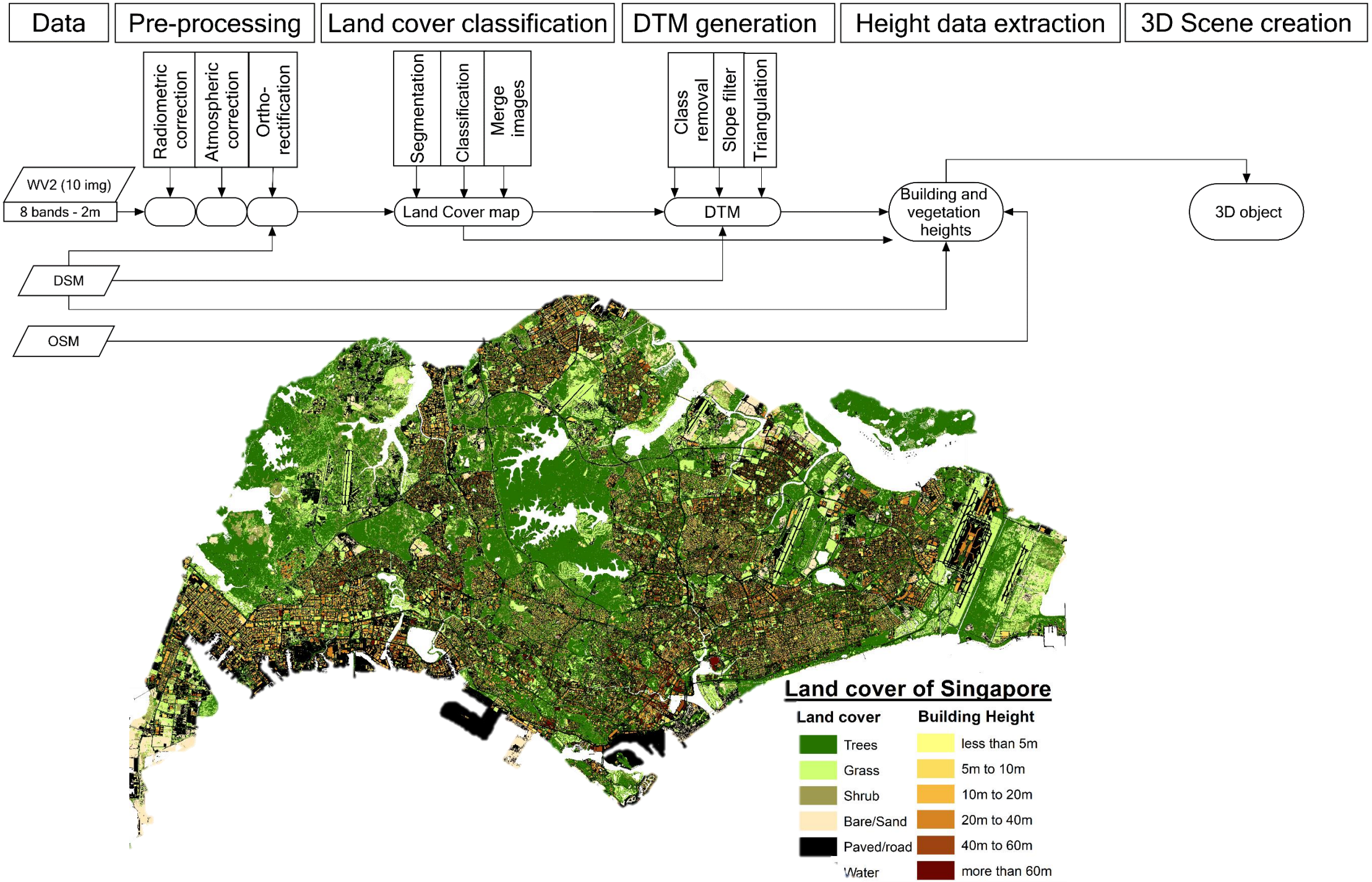


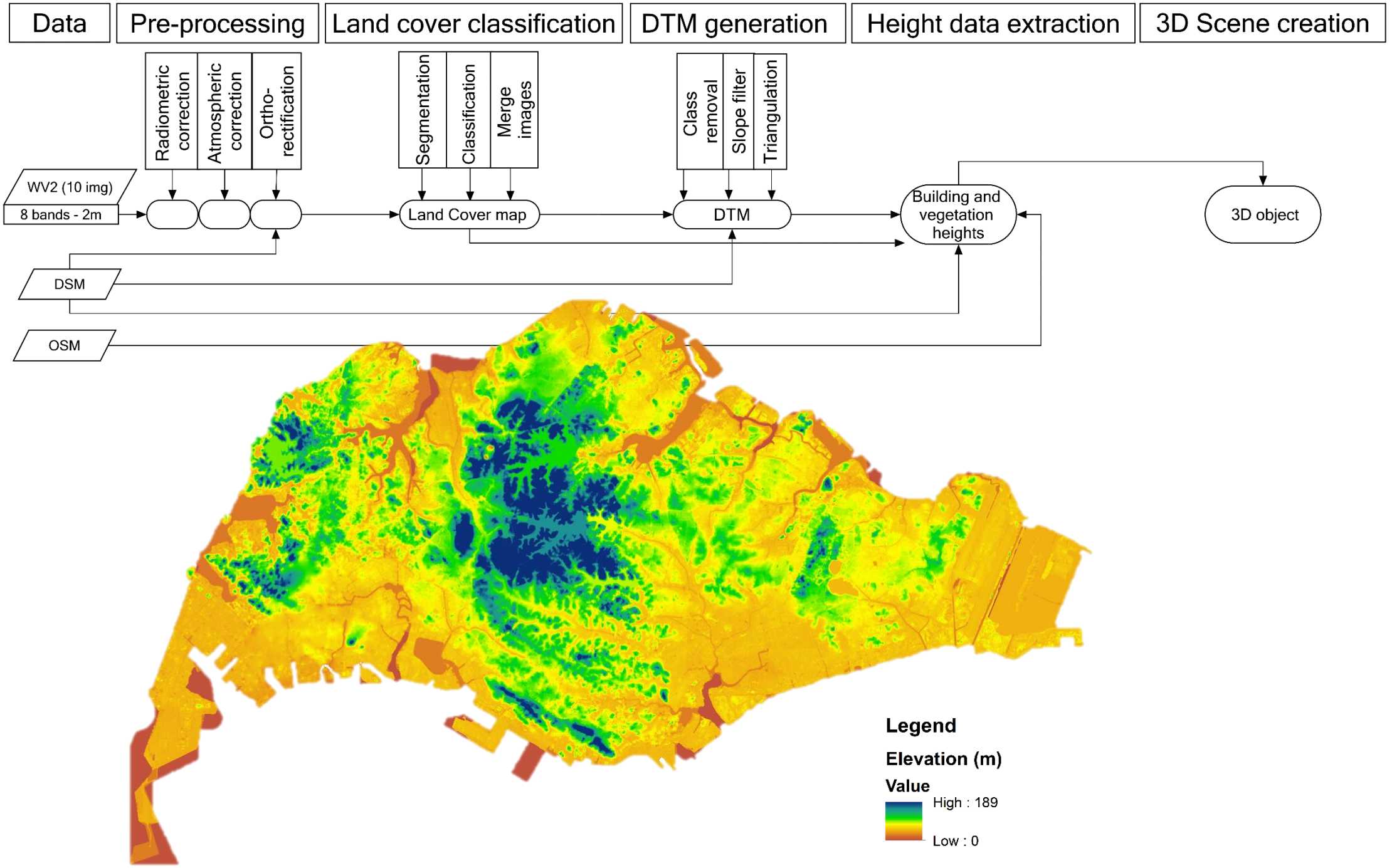
GIS layers

3-D scene reconstruction

Radiative transfer modelling

Radiative budget time series analysis


Data
Pre-processing
Land cover classification
DTM generation
Height data extraction
3D Scene creation
Radiometric correction
Atmospheric correction
Ortho-rectification
Segmentation
Classification
Merge images
Class removal
Slope filter
Triangulation
WV2 (10 img)
8 bands - 2m
Land Cover map
DTM
Building and vegetation heights
3D object
DSM
OSM
Land cover of Singapore
Land cover
Trees
Grass
Shrub
Bare/Sand
Paved/road
Water
Building Height
less than 5m
5m to 10m
10m to 20m
20m to 40m
40m to 60m
more than 60m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WV2 (10 img)
8 bands - 2m
Land Cover map
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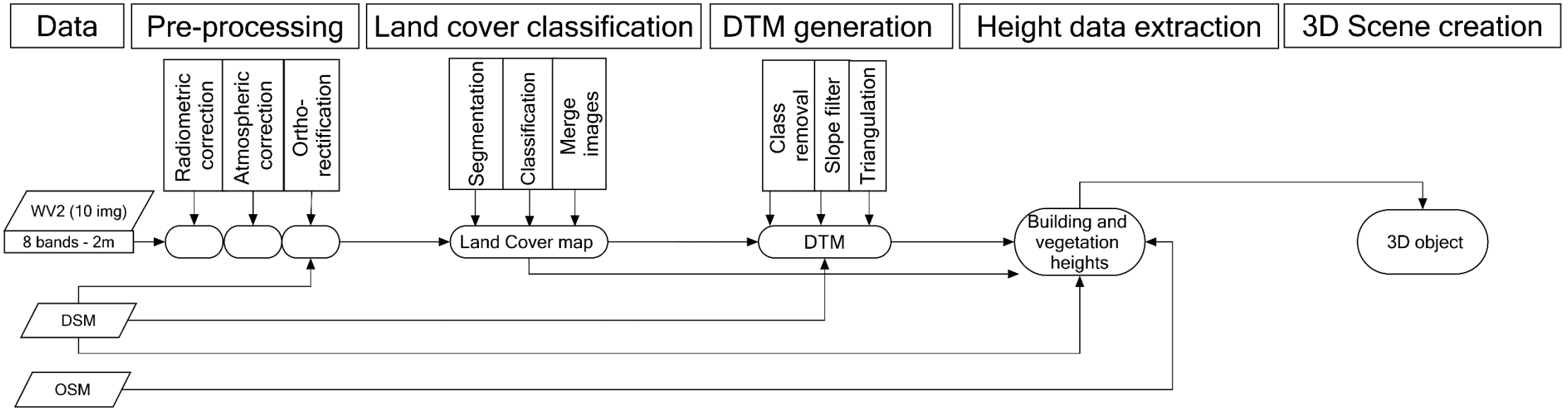
Building and vegetation heights
3D object
DSM
OSM
Legend
Elevation (m)
Value
High : 189
Low : 0



T1 Residential low rise

Land Cover	Bulidings
Ground: 49%	Volume: 1351641m3
Built: 35%	External surface: 408477m2
Trees: 16 %	

T2 Industrial low rise

Land Cover	Bulidings
Ground: 51%	Vol: 1939054m3
Built: 34%	External surface: 249922m2
Trees: 15%	

T3 HDB mid rise

Land Cover	Bulidings
Ground: 54%	Vol: 1442830m3
Built: 13%	External surface: 266467m2
Trees: 33%	

T1.0 Residential low rise LAD = 0

Land Cover	Bulidings
Ground: 65%	Volume: 1351641m3
Built: 35%	External surface: 408477m2
Trees: 0%	

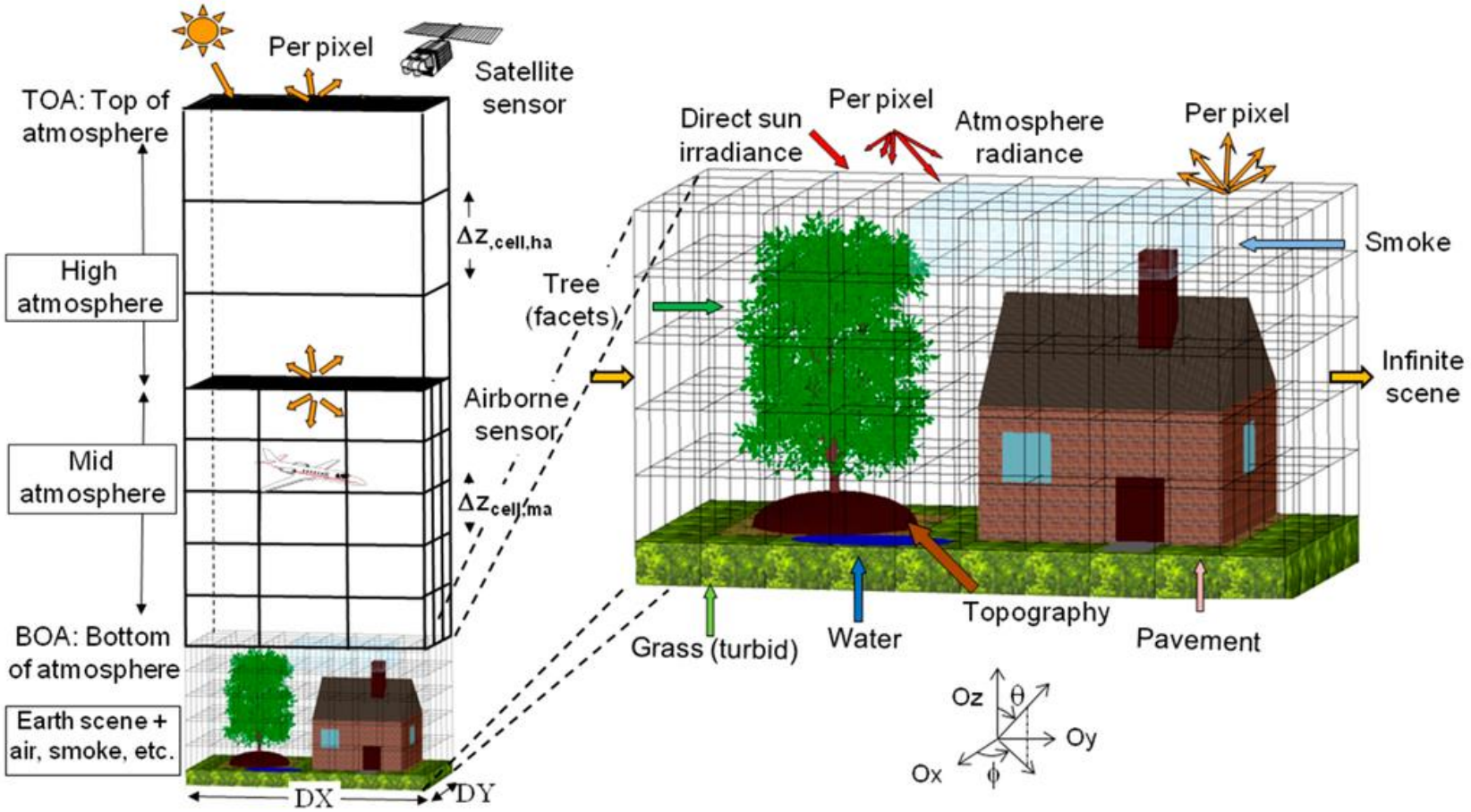
T4 Residential high rise

Land Cover	Bulidings
Ground: 48%	Vol: 1549404m3
Built: 7%	External surface: 261703m2
Trees: 45%	

T5 Secondary forest

Land Cover	Bulidings
Ground: 46%	Vol: 20763m3
Built: <1%	External surface: 5575m2
Trees: 53%	

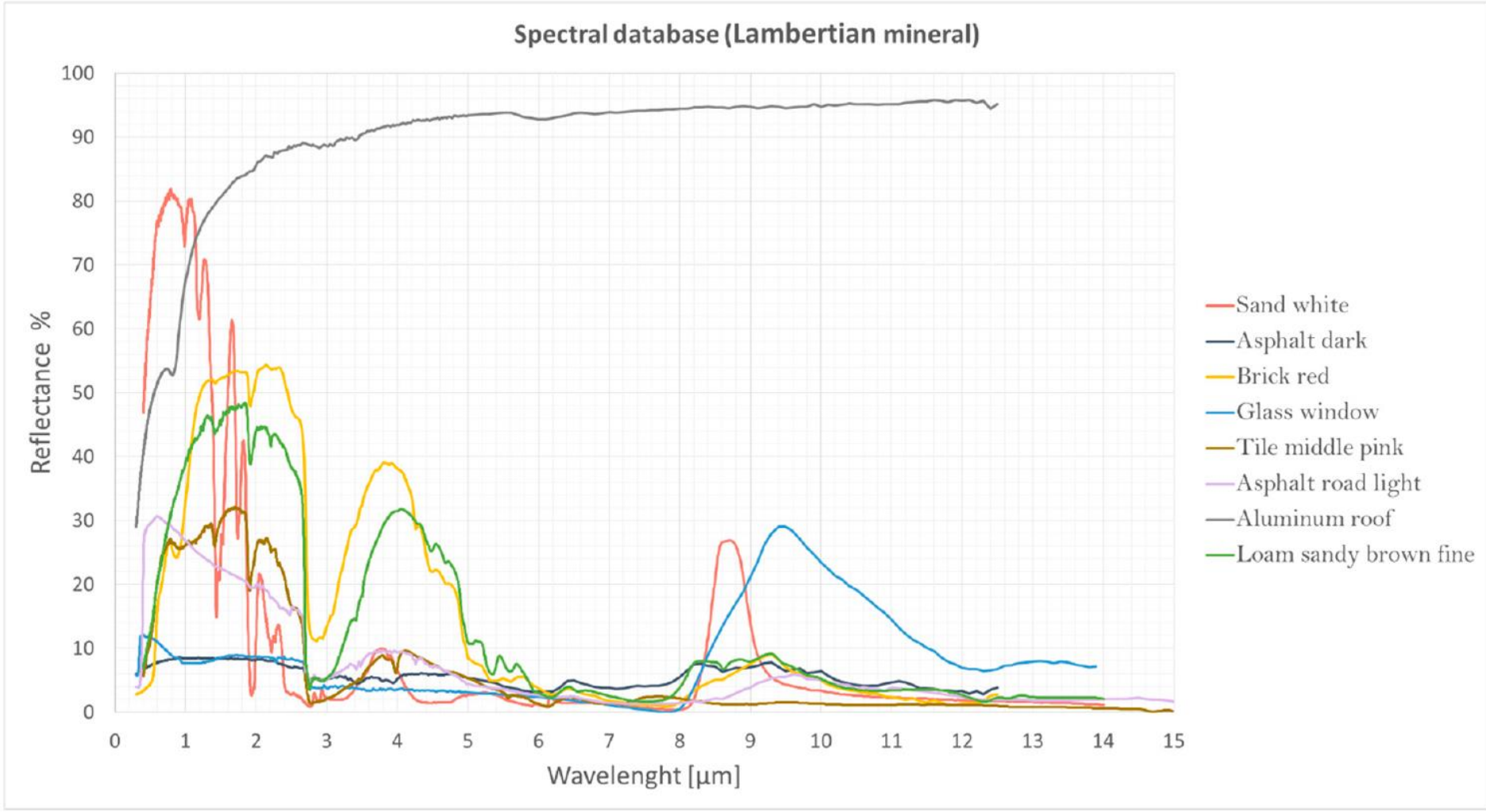
Physical-based 3-D Radiative Transfer Model



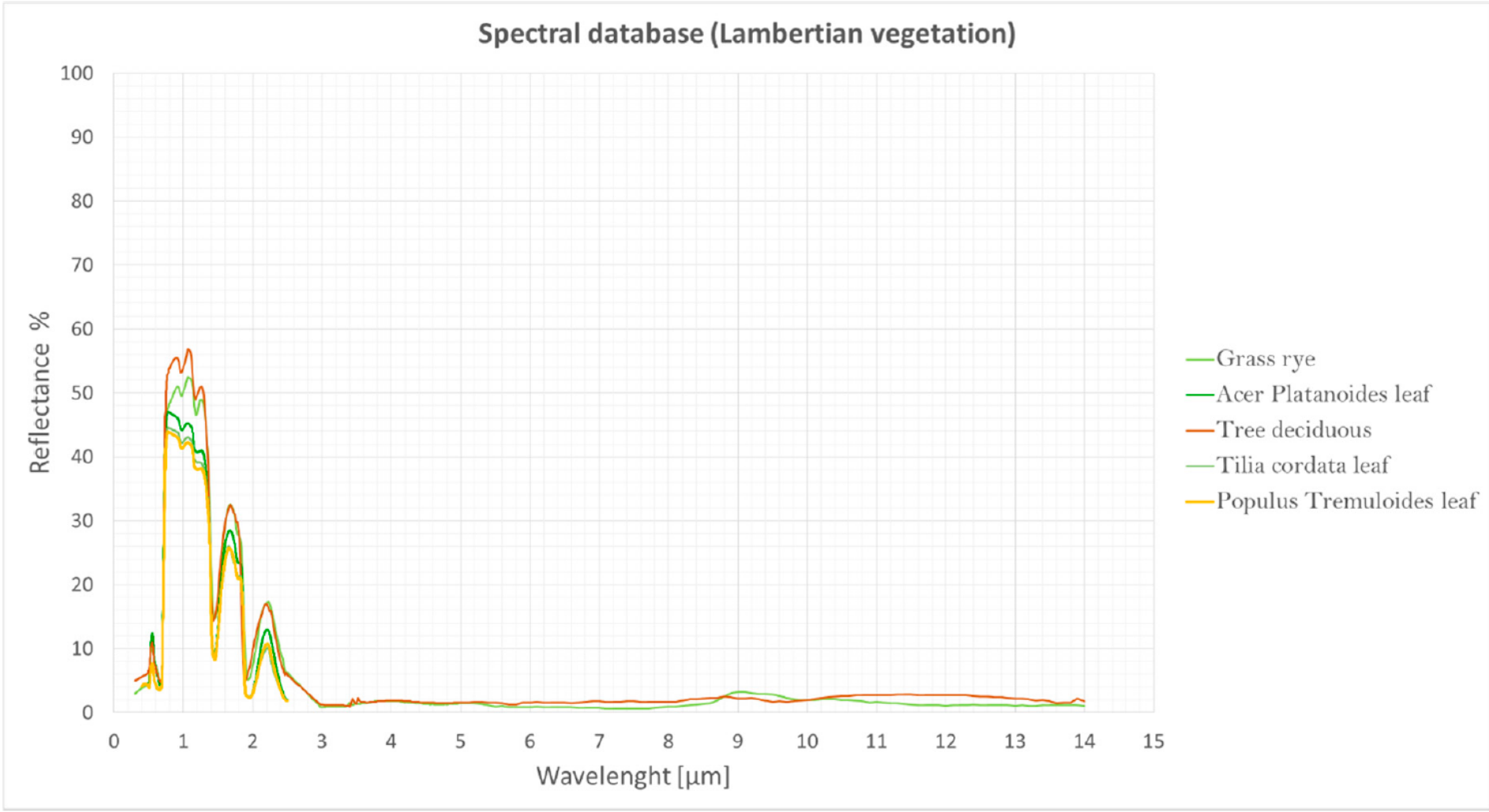
Discrete Anisotropic Radiative Transfer (DART) model, https://dart.omp.eu/#/

- Models multiple scatterings between simulated scene elements in 3-D
- spectral domain extends from ultraviolet to thermal infrared
- Detailed vegetation parameters
- Surface optical properties for construction materials and vegetation

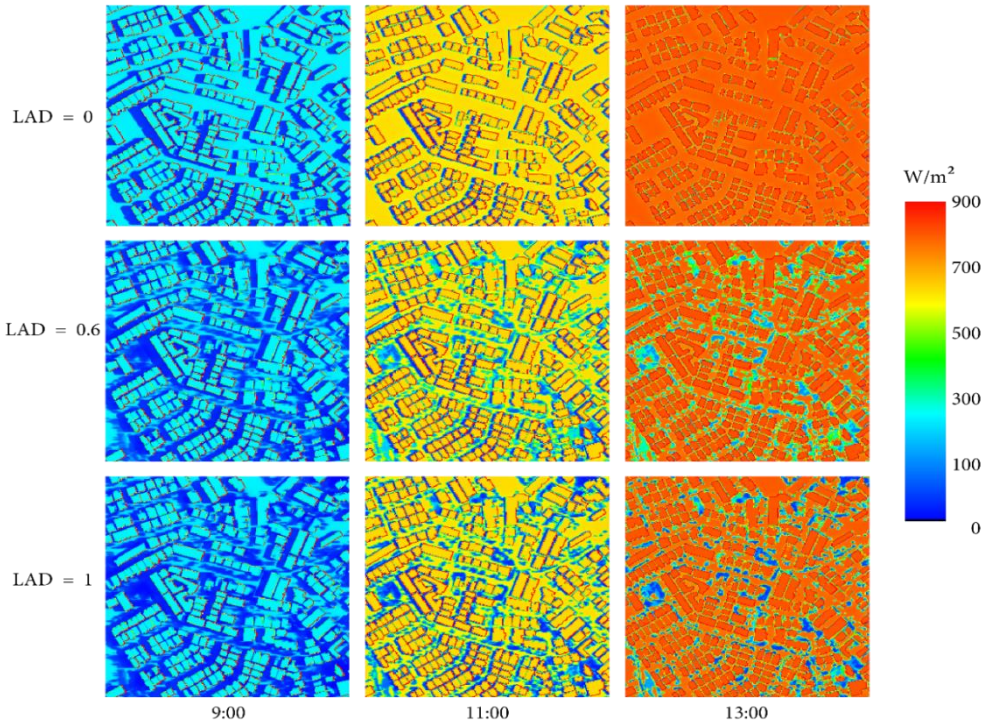
Spectral reflectance of construction materials from DART database



Spectral reflectance of construction materials from DART database



Absorbed radiation by ground and buildings for different Leaf Area Density values

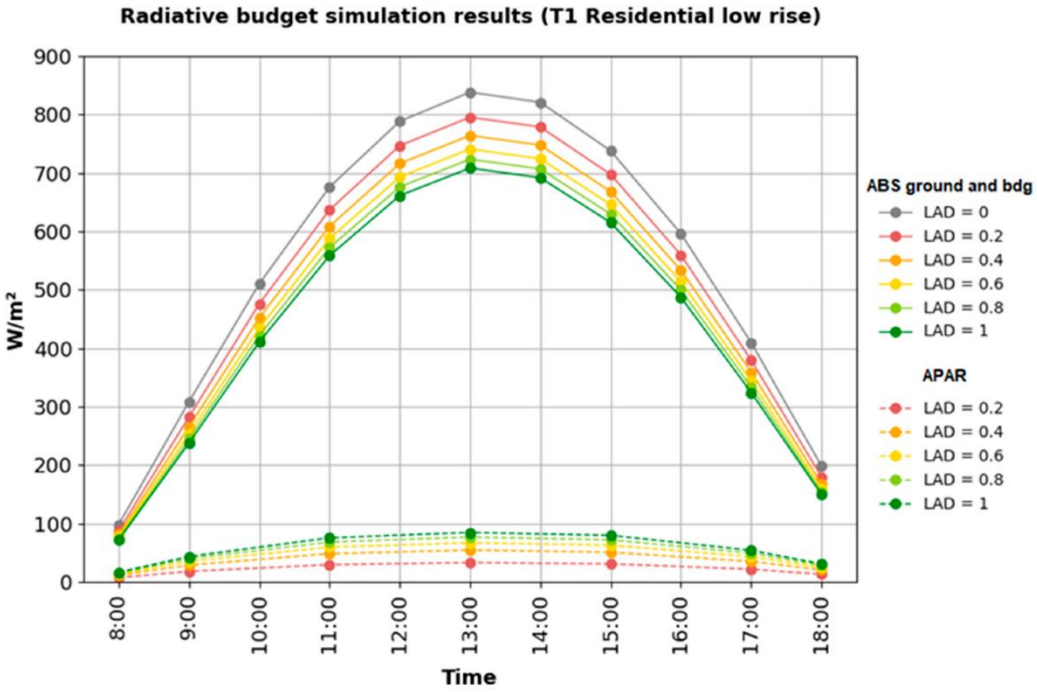


Land Cover

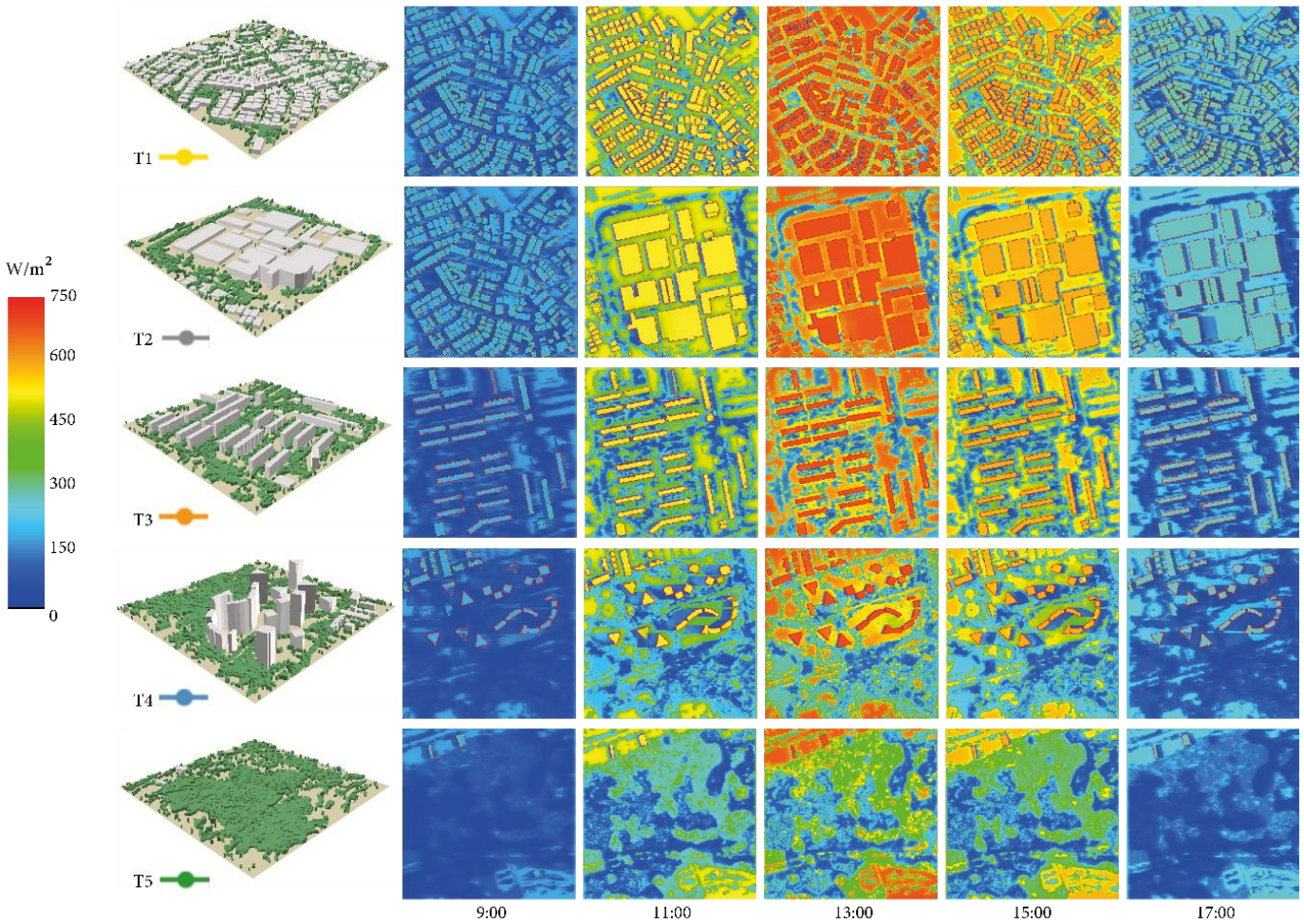
Ground: 49%
Built: 35%
Trees: 16 %

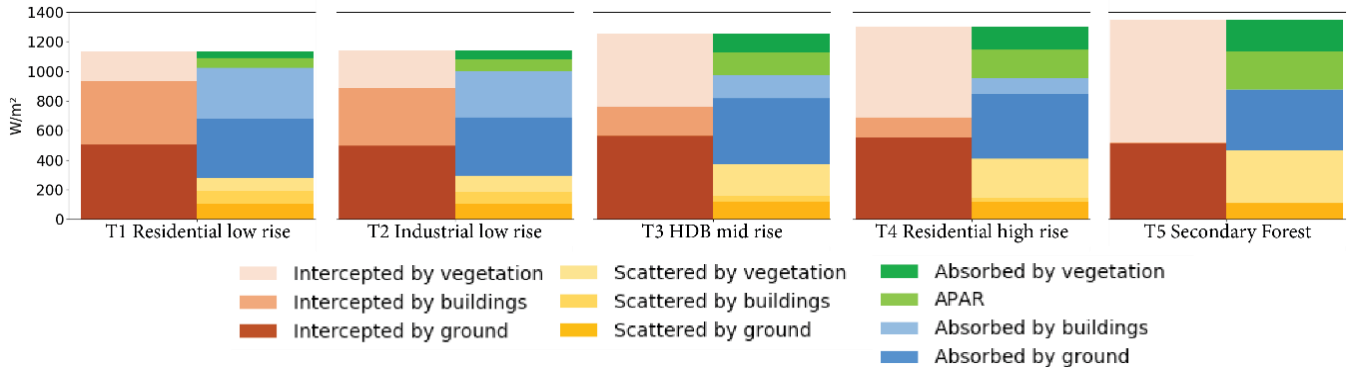
Bulidings

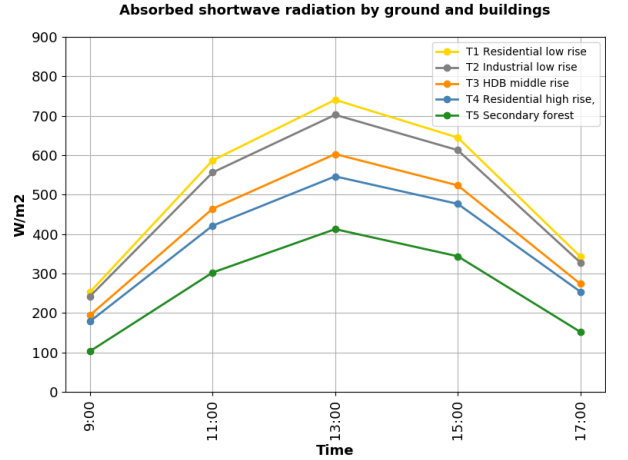
Volume: 1351641m3
External surface: 408477m2

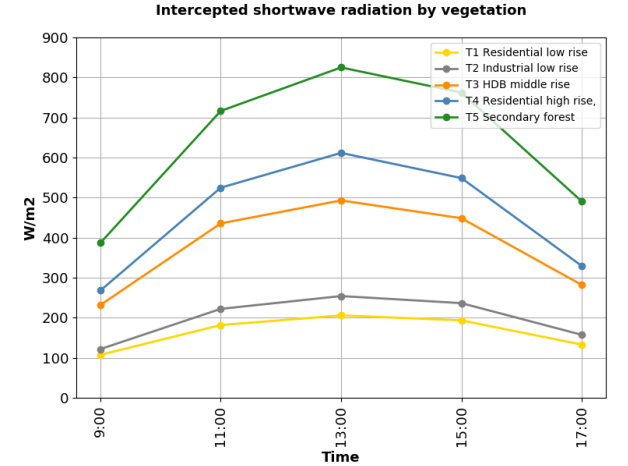


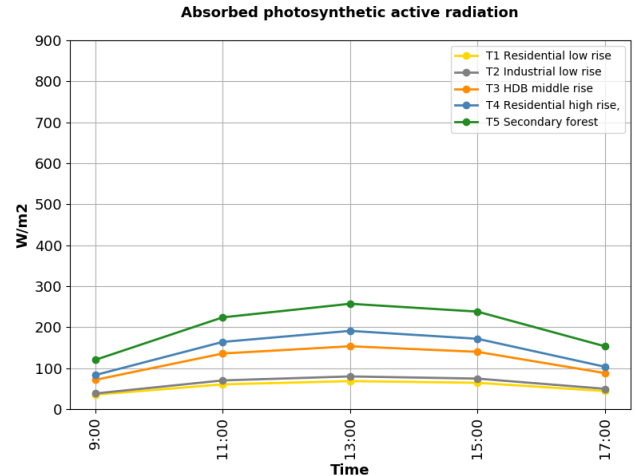
Although T1 has a relatively low tree cover, the presence of trees in the scenes accounted for a reduction of 15% of the absorbed radiation by the buildings and the ground, when LAD = 1


W/m²
750
600
450
300
150
0
T1
T2
T3
T4
T5
9:00
11:00
13:00
15:00
17:00


W/m²
1400
1200
1000
800
600
400
200
0
T1 Residential low rise
T2 Industrial low rise
T3 HDB mid rise
T4 Residential high rise
T5 Secondary Forest
Intercepted by vegetation
Intercepted by buildings
Intercepted by ground
Scattered by vegetation
Scattered by buildings
Scattered by ground
Absorbed by vegetation
APAR
Absorbed by buildings
Absorbed by ground


Absorbed shortwave radiation by ground and buildings
W/m2
Time
9:00
11:00
13:00
15:00
17:00
T1 Residential low rise
T2 Industrial low rise
T3 HDB middle rise
T4 Residential high rise,
T5 Secondary forest

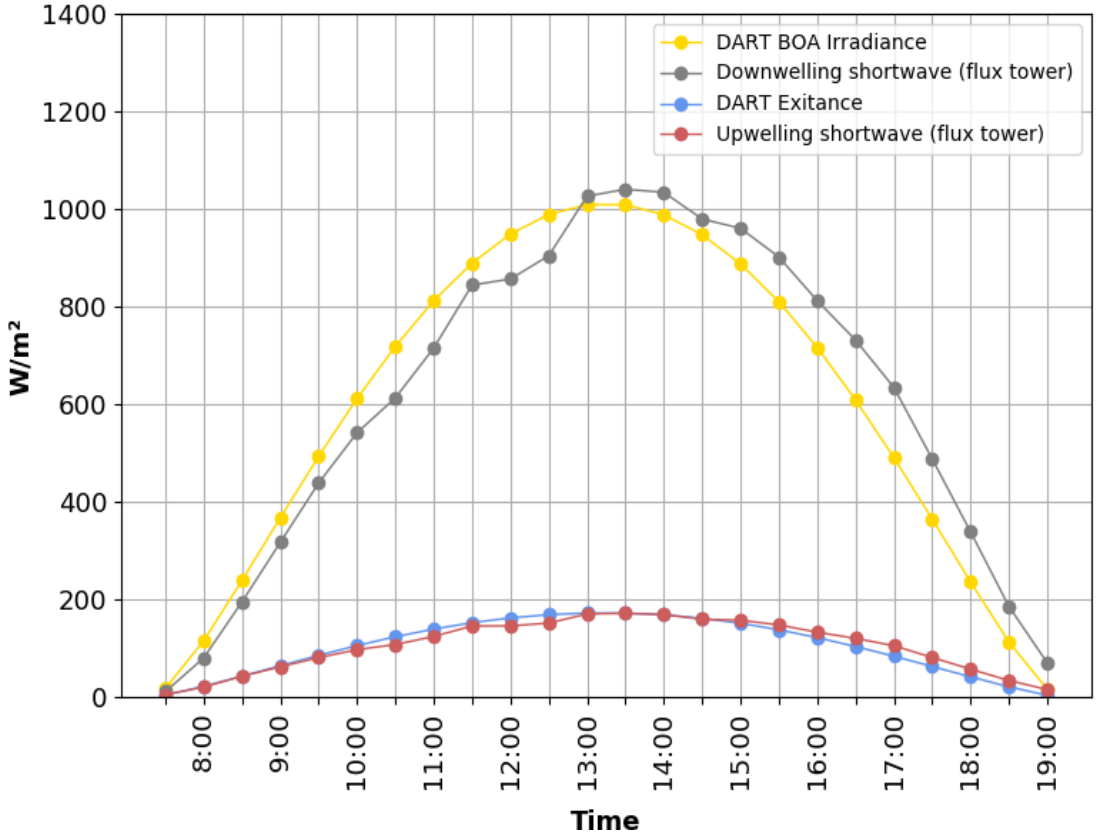

Intercepted shortwave radiation by vegetation
W/m2
Time
9:00
11:00
13:00
15:00
17:00
T1 Residential low rise
T2 Industrial low rise
T3 HDB middle rise
T4 Residential high rise,
T5 Secondary forest


Absorbed photosynthetic active radiation
W/m2
Time
9:00
11:00
13:00
15:00
17:00
T1 Residential low rise
T2 Industrial low rise
T3 HDB middle rise
T4 Residential high rise,
T5 Secondary forest

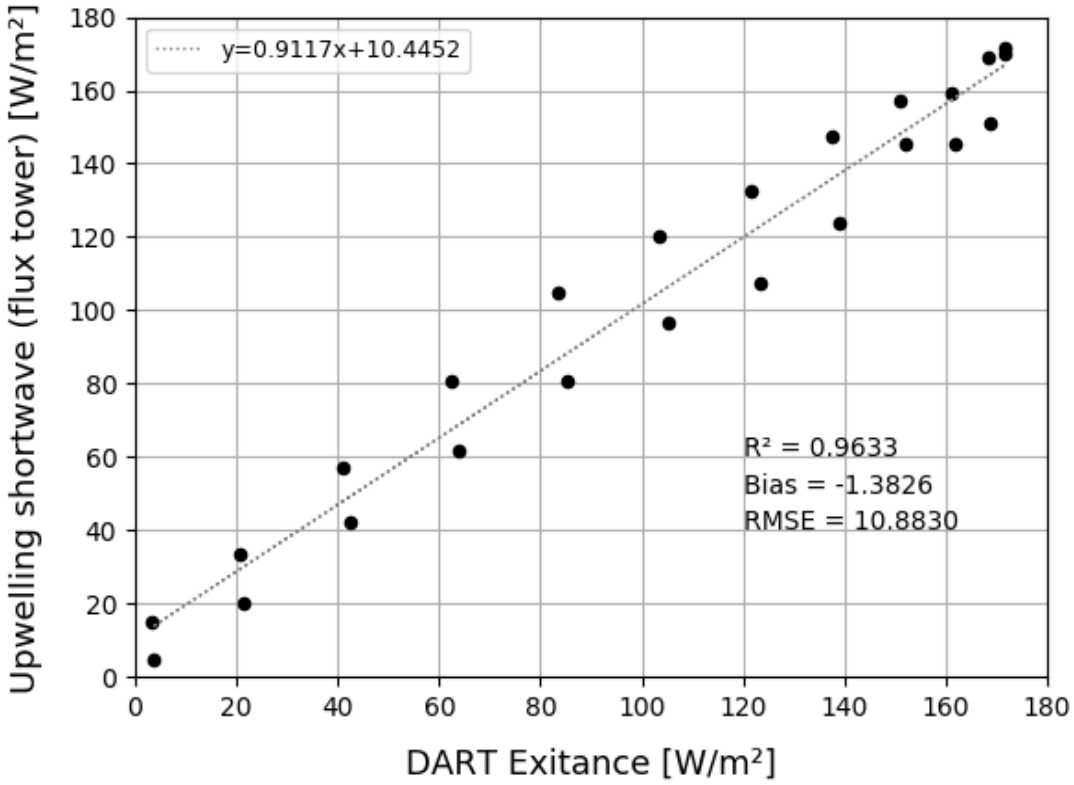
Validation using Net Radiometer

(Telok Kurau flux tower, Singapore)

a

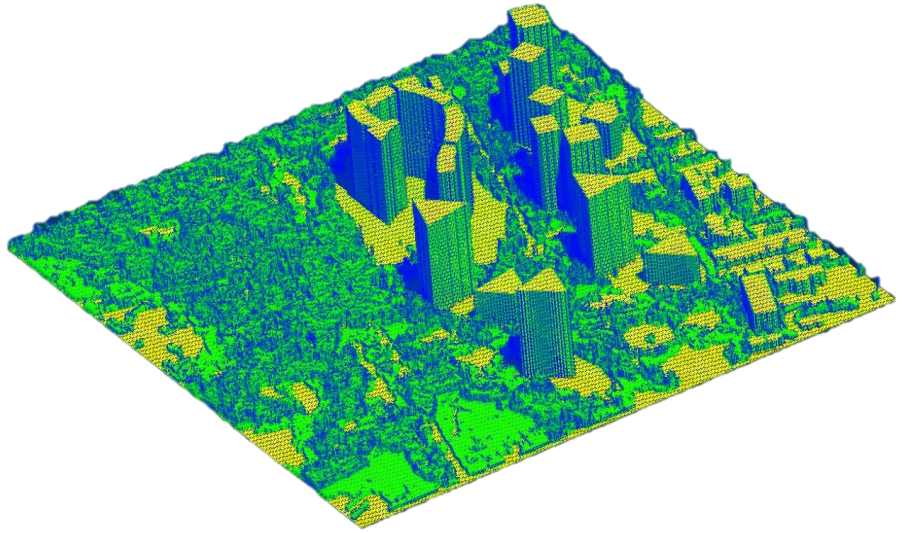


b

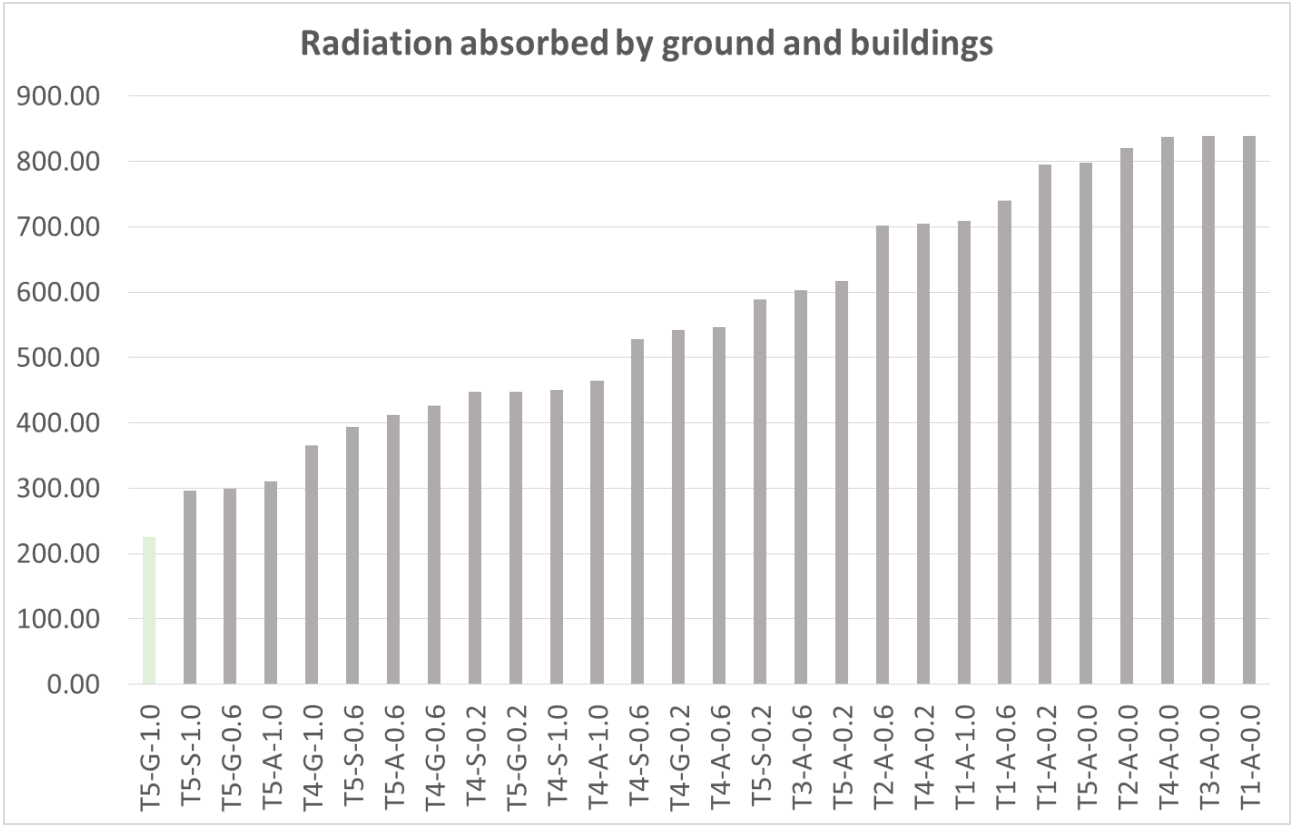


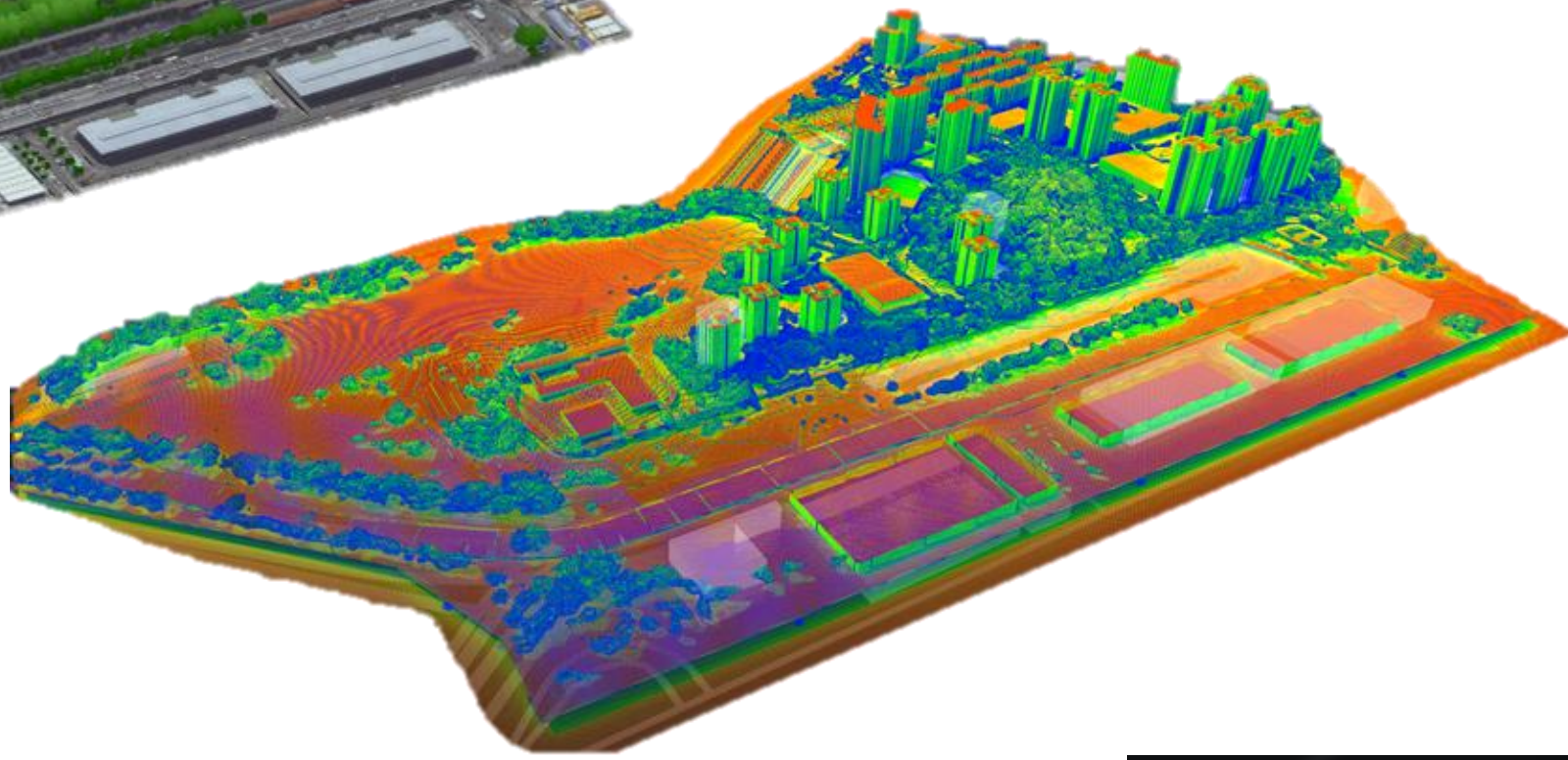
(a) Time series of DART simulated bottom of atmosphere (BOA) irradiance and exitance; and upwelling and downwelling shortwave radiation obtained from net radiometer measurements. (b) Scatterplot of DART simulated exitance against upwelling shortwave

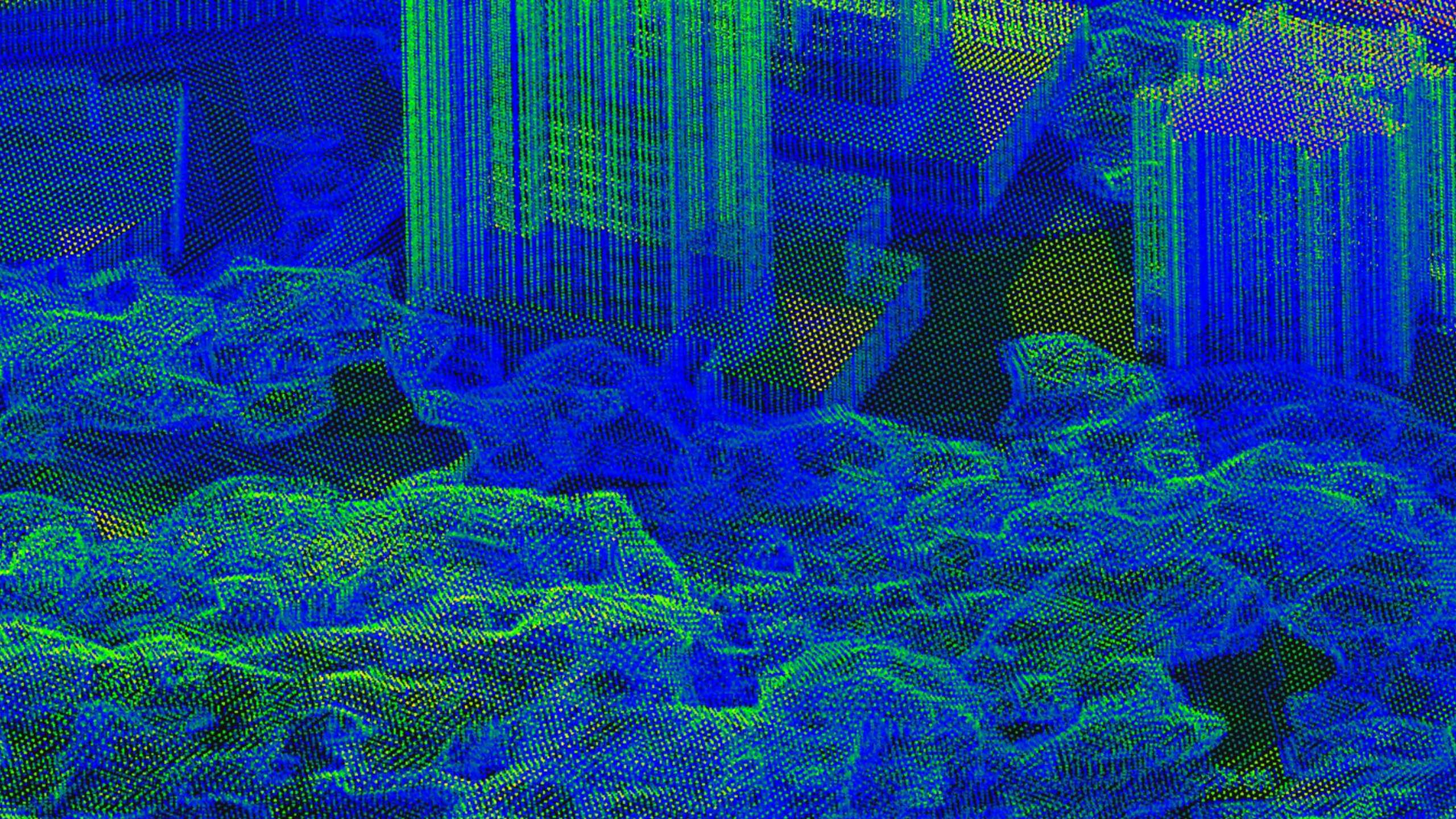
Summary of results



Typology	Ground cover	LAD				Code	Absorbed by buildings and ground at 13:00	Difference
T5	Grass				1.0	T5-G-1.0	225.53	0.00
T5	Soil				1.0	T5-S-1.0	296.55	71.02
T5	Grass			0.6		T5-G-0.6	299.43	73.90
T5	Asphalt				1.0	T5-A-1.0	310.33	84.80
T4	Grass				1.0	T4-G-1.0	366.09	140.56
T5	Soil			0.6		T5-S-0.6	394.27	168.74
T5	Asphalt			0.6		T5-A-0.6	412.54	187.01
T4	Grass			0.6		T4-G-0.6	426.28	200.75
T4	Soil		0.2			T4-S-0.2	446.97	221.44
T5	Grass		0.2			T5-G-0.2	446.97	221.44
T4	Soil				1.0	T4-S-1.0	450.37	224.84
T4	Asphalt				1.0	T4-A-1.0	463.89	238.36
T4	Soil			0.6		T4-S-0.6	528.25	302.72
T4	Grass		0.2			T4-G-0.2	541.84	316.31
T4	Asphalt			0.6		T4-A-0.6	546.30	320.77
T5	Soil		0.2			T5-S-0.2	589.02	363.49
T3	Asphalt			0.6		T3-A-0.6	602.90	377.37
T5	Asphalt		0.2			T5-A-0.2	617.07	391.54
T2	Asphalt			0.6		T2-A-0.6	702.42	476.89
T4	Asphalt		0.2			T4-A-0.2	704.40	478.87
T1	Asphalt				1.0	T1-A-1.0	708.37	482.85
T1	Asphalt			0.6		T1-A-0.6	740.34	514.81
T1	Asphalt		0.2			T1-A-0.2	795.37	569.84
T5	Asphalt	0.0				T5-A-0.0	798.48	572.95
T2	Asphalt	0.0				T2-A-0.0	820.65	595.13
T4	Asphalt	0.0				T4-A-0.0	837.20	611.67
T3	Asphalt	0.0				T3-A-0.0	838.16	612.63
T1	Asphalt	0.0				T1-A-0.0	838.19	612.66




0
350 W/m



Conclusions

- This research contributes to a better understanding of the effect of vegetation and urban form in the radiative budget of a city.

- Our approach can be used for neighborhood-scale analysis, at any desired location of a city, allowing to test scenarios with varying surface materials and vegetation properties.

- The data used in this study are either open or commercially available, which allows replication in other cities.

Future work

- Spatio-temporal analysis of Mean Radiant Temperature (Tmrt) based on DART radiative budget.
- Outdoor Thermal Comfort

Thank you!

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